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**Cover Page Footnote**

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# Agent-Based Models of the Green Dot Bystander Violence Prevention Program on College Campuses

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**Abstract**
Despite the hard work of a diverse collection of organizations committed to violence prevention, the prevalence of rape, abuse, and other forms of interpersonal violence remains startling, especially on college campuses. Here we present an agent-based model (ABM) of interpersonal violence rooted in the philosophy of the Green Dot Bystander Training Program, in the hopes of providing insight into ways in which training of students can be improved so that intervention attempts are more effective. Two models, with and without adaptive behaviors, are studied under two population sizes. Through sensitivity testing, various outcomes are analyzed to measure the effectiveness of each intervention strategy. The scenarios that result in the smallest relative number of violent acts are those with a denser population, while the adaptive models produce unexpected results that prompt questions about human behavior and our tendency toward bystander intervention.

**Keywords:** agent-based modeling, bystander violence prevention, Green Dot, sensitivity testing, NetLogo

## 1 Introduction

An act of interpersonal violence ensues when one harms another through physical, psychological, emotional or sexual means. The act may occur in a variety of environments ranging from the workplace, the social scene, and, of particular interest to the authors, hubs of young adults: academic institutions such as colleges and universities. The ramifications of interpersonal violence are often immeasurable, and its effects are ever more detrimental and noxious due to physical and psychological repercussions the survivor may face long after the incident has occurred.

In recent years, the difficulty of tackling the issue of interpersonal violence on college campuses nationwide has come to light. Considering that campus crime statistics are in some instances underreported [8], the numbers available are startling. It has been reported that an estimated 20% to 25% of women and approximately 3.3% of men in institutions of higher education will have been the target of interpersonal violence at least once during their four years at university [3]. In addition, 90% of those personally harmed knew the perpetrator [3]. While these figures are disquieting, numerous organizations across the country—End Rape on Campus [2], Know Your IX [7], Green Dot, etc. (GDE) [4], to provide just a few—are working to find a solution to the issue.

Organizations such as GDE have made it their mission to tackle the problem of interpersonal violence by using techniques such as bystander training sessions and educational overview presentations designed to educate and empower students to take a stand against violence and intervene (perform what GDE terms a "green dot") when they recognize the early stages of a potentially violent act. According to GDE, their efforts have effectively reduced the number of incidences of interpersonal violence (what GDE would call "red dots") on college campuses [1]. Due to the complex nature of social interactions, especially around the issue of interpersonal violence, there can be many factors that play into the effectiveness of bystander intervention strategies. This is precisely where mathematical modeling can provide greater insight. In order to further aid organizations such as GDE in their fight to stop interpersonal violence, a system that models and predicts the efficacy of strategies/preventative methods is critical.

In this paper, we develop and analyze two Agent Based Models (ABMs) of interpersonal violence using NetLogo, an ABM software platform [10]. ABMs are small-scale models that imitate a larger environment. An ABM creates agents to represent various types of individuals, including people, animals, diseases, etc., and allows these agents to interact with one another and their environment according to a set of user-defined rules. Since agents are autonomous, they have the capacity to adapt and alter their behavior throughout the course of a single simulation run; in doing so, peculiar patterns may emerge. The

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primary goal of our modeling effort is to capture realistic social behaviors among college students, starting with a simplified model and then moving to a more complex model that incorporates adaptive behavior, in order to make predictions about effective tools for violence prevention. In what follows, we provide details of our two models in an effort to enable the reader to more deeply understand the inner workings of the models and how we can use model outputs to further improve violence intervention strategies.

Section 2 elaborates on the key assumptions and specific details of the two models, including their algorithms and implementation in NetLogo. In Section 3 we present results and discussion of sensitivity testing, where we vary different model parameters to observe overall changes in model behavior. In Section 4 we explore the ways in which this model can be used to strengthen Green Dot programs on college campuses. We conclude with future directions in Section 5.

# 2 The Agent-Based Models

In the following we provide details for our two ABMs of interpersonal violence using the formatting recommendations from the Overview, Design concepts, and Details (ODD) protocol for ABMs by Grimm et al. [6]. The ODD protocol is now the standard for describing ABMs in the literature as it provides a template for making model descriptions more understandable and reproducable.

## 2.1 Purpose

These models investigate and evaluate various strategies related to the prevention of acts of interpersonal violence among college students. They determine a strategy's effectiveness by comparing the number of successful interventions to the number of potentially violent situations and explore the role that peers play in influencing those around them to take positive action. The models also explore threshold points. For example, if we assume students are more likely to intervene in a potentially violent situation if they have seen someone else do so, at what percentage do the initial interveners have to take action in order to produce a statistically significant increase in peer-induced interventions?

These models could also be manipulated to investigate similar social interactions within populations outside of a college campus. This includes, but is not limited to, other communities, such as YWCAs and military bases, where the Green Dot Program is established or is planning on becoming established [5].

## 2.2 Entities, State Variables, and Scales

The agents in these models are college students, each of which is characterized by a single parameter we call "status": green dotters, red dotters, or neutral dotters. We assume that a green dotter is an individual who has taken the full, 7-hour Green Dot bystander training at their university. Likewise, we assume that someone who is seeking to harm other individuals will always be the same, a red dotter. A red dotter is an individual that, if successfully coupled with another non-red dotter (e.g., a green dotter or a neutral dotter), will always seek to initiate a violent interaction. A neutral dotter has different roles in each of the models. In the simple model (see Model SM in Subsection 2.3), they simply move around the environment randomly and will neither intervene nor initiate any sort of violent coupling. In the adaptive behavior model (see Model AM in Subsection 2.3), they may gain a tendency to intervene in a potentially violent situation if they have been a witness to a previous intervention.

Each of these agents has 3 parameters, also referred to as *state variables*, that characterize their behavior: `coupling-tendency`, `resting-tendency`, and `intervening-tendency`. The `coupling-tendency` controls the likelihood of a red dotter and another non-red dotter entering into some form of close connection, which may escalate into a violent act if not stopped by a green dot intervention within a specified amount of time. This tendency is the same for all of the agents, and the sex of each individual is currently not taken into consideration.

The `resting-tendency` is the tendency for an agent to decide to stop and observe a potentially violent situation, while the `intervening-tendency` is the tendency for an agent to actually intervene in this situation after they have already decided to stay and observe. In both models, the `intervening-tendency` is fixed at 0 for red dotters and neutral dotters and is set to a user-defined value that is the the same for all green dotters. The `resting-tendency` for red dotters is also kept at 0 in both models. In the simple model, this parameter is 0 for neutral dotters; however, in the adaptive behavior model, this parameter is initialized at the same user-defined value as that for green dotters.

The size of the environment is chosen to simulate an average sized lower level at a house party. The environment is two-dimensional and is divided up into a grid of patches. We choose each patch to be 1 ft $\times$ 1 ft, and the entire environment is 41 $\times$ 41 patches. Our environment therefore represents 41 ft $\times$ 41 square feet, which would be an average size for the lower level of a house. A person's location is initiated randomly and is described via their patch coordinates. The environment is closed and thus does not wrap around.

Each time step (also known as a *tick*) is equal to 2 minutes. The model runs for 120 ticks so that one full model run simulates 4 hours, or about the length of a typical house party.

## 2.3 Process Overview and Scheduling

The two models will henceforth be labeled as Model SM, the simple model, with no interventions from neutral dotters, and Model AM, the adaptive behavior model, where neutral dotters can increase their likelihood to intervene as they witness more interventions from others. See Design Concepts (Subsection 2.4) for a detailed description of these models' components.

Once the user sets values for number of red, green, and neutral dotters and for the three state variables `intervening-tendency`, `resting-tendency`, and `coupling-tendency`, dotters are initialized on random patches throughout the environment and are randomly selected to be green, red, or white (for neutral dotters) according to the values previously chosen by the user. In what follows, we outline the schedule and processes evaluated at each tick.

Agent movement: In random order, each agent is asked if they are coupled to another agent. If the currently selected agent is not coupled to another agent, it is asked to evaluate the `move` procedure (see Subsection 2.6); otherwise, if it is coupled, it remains on its current patch.

Agent coupling: Red-dotters are the only agents who can initiate coupling. If a red dotter is already coupled, the code moves on to the next red dotter. If the red dotter is uncoupled it will evaluate the `couple` procedure (see Subsection 2.6). If the current red dotter successfully couples, the patches behind the couple turn grey.

Progression of violence: The length of time for which the couple has been together is checked with the `couple-length` counter, which records the number of ticks that two agents have been coupled together. If the couple has been together for 8 ticks (16 minutes), an incidence of violence is recorded and the two dotters uncouple. Otherwise, the code will search for a nearby green dotter (in a 4-patch radius) to serve as a potential intervener for this couple, in the event that such a green dotter does not already exist for this couple.

If a green dotter has been selected as a potential intervener for a couple, they turn their patch color to blue (see Figure 1) and decide whether or not to stay and observe the situation. A floating-point number ranging from 0.0 to 10.0 is randomly generated, and if that number is larger than the `resting-tendency`, the couple increases their `couple-length` by 1 and the green dotter is no longer identified as a potential intervener for the couple. If that number is less than the user-defined `resting-tendency`, then the green dotter will stay on its current patch, no longer randomly moving throughout the environment, and will remain the potential intervener for the couple.

The green dotter, who has decided to stay and observe the situation, next decides whether or not to intervene. A floating-point number ranging from 0.0 to 10.0 is randomly generated, and if that number is less than the user-defined `intervening-tendency` of the green dotter, then the green dotter will intervene. If the green dotter intervenes, the red dotter and its partner evaluate the `uncouple` procedure and their `couple-length` is set to 0. An intervention is recorded. If the green dotter does not intervene, the couple increases their `couple-length` by 1. This green dotter will remain the potential intervener for this couple until the green dotter decides to stop watching the couple (in a later tick), or until the green dotter finally decides to intervene (in a later tick), or until the couple has been together for 8 ticks, signaling a violent act and the uncoupling procedure.

Advance time: The tick counter is advanced by one. If the current tick equals the user-defined maximum number of ticks, the simulation is stopped and the final number of couplings, interventions, and incidents of violence are printed. Otherwise, the above processes are repeated.

These processes outline the algorithm for the simplest version of the model, Model SM. However, this simple model does not incorporate adaptive behavior of untrained individuals (neutral dotters in our model). One of the foundational components to the Green Dot training program is that trained green dotters will lead by example. The idea is that as other students witness green dot interventions, they are more likely to intervene in the future, regardless of whether or not they have received the full training [4]. Therefore, we improved upon our initial model by adding an adaptive component that allows neutral dotters to gain intervention abilities. We elected not to allow red dotters to gain any intervening capability since the current assumption is that these individuals only seek to do harm, not to prevent violence.

A neutral dotter can increase their intervention tendency if they have witnessed an intervention from another green or neutral dotter. The variable we use to denote this increase is called `intervening-slack`. The value of this parameter is initialized at 0 for all neutral dotters and increases by 1 for a particular neutral dotter each time that neutral dotter is within a 4-patch radius of an intervention. If, for example, a neutral dotter has gained an `intervening-slack` equal to 2, meaning they have witnessed two previous interventions, then they have a chance of being selected as the `potential-intervener`. They will decide to stay and observe the situation with the same probability as every other green dotter, governed by the value of `resting-tendency`. If they decide to stay, then there is a 20% chance (since their `intervening-slack` = 2) that they will intervene. It is possible that this behavior of gaining `intervening-slack` is binary, but we chose to make it proportional to the number of interventions witnessed because we are making the assumption that the more an individual witnesses others intervene, the more courage and knowledge they will have to intervene in the future.

In Section ?? we perform a sensitivity analysis for both models, using two different population sizes for each, to gain insight into how the adaptive behavior and population size influence interventions.

## 2.4 Design Concepts

**Emergence:** The model's primary outputs are `num-interventions` and `num-couples`, which are the number of interventions and total number of couples formed throughout the simulation, respectively. The ratio of the number of interventions divided by the total number of couples is later calculated as a measure of the effectiveness of the intervention strategy. This ratio is presumably affected by (a) the `coupling-tendency`, (b) the `resting-tendency`, (c) the `intervening-tendency`, and (d) the ratio of agent types (red, green, and neutral dotters) in the population. It is also reasonable to believe this ratio would be affected by whether the model at hand is SM or AM, for in Model AM neutral dotters may acquire intervention tendencies.

**Adaptation:** Model SM does not allow the agents to adapt, but Model AM does. In Model SM, only green dotters can intervene, and the probability of them intervening is predetermined and fixed by the user-defined `intervening-tendency`. In Model AM, neutral dotters can acquire `intervening-slack` in reaction to witnessing a successful intervention (see Subsection 2.3). Here, green dotters are given an initial `intervening-slack` equal to the user-defined `intervening-tendency`, and for the remainder of the simulation, the `intervening-slack` value is used for both green and neutral dotters in determining likelihood of an intervention. Thus, in Model AM both green dotters and neutral dotters can increase their individual `intervening-slack` as they witness interventions. For both models, `coupling-tendency` and `resting-tendency` are user-defined constants that do not change throughout the simulation.

**Sensing:** Once green dotters (and neutral dotters in Model AM) are within a 4-patch radius of a couple (i.e., a potentially dangerous situation), it is assumed that they know that this couple is there.

**Interaction:** All of the interactions in these models are direct. Red dotters interact with non-red dotters to form a couple based upon the generally applied `coupling-tendency`. In both models, green dotters interact with these couples, as green dotters will choose to stay next to the couple at a rate determined by the `resting-tendency` and then will choose to intervene (thus breaking up the couple) at a rate determined by the `intervening-tendency`. In Model AM, neutral and green dotters can gain `intervening-slack` if they witness (i.e., are in a 4-patch radius of) a successful intervention and will then have the opportunity to interact with a couple. Additionally, because a potential-intervener can only be identified for a couple if the agent is within 4 patches (translated to 4 feet) of the couple, this agent could feasibly watch multiple couples in our model. However, if the population became dense enough this could be problematic and unrealistic. In the future, we plan to investigate the possibilities of limiting one couple per intervener, but allowing multiple interveners per couple.

**Stochasticity:** Stochastic functions are used to initialize individual locations and the status of each agent (red, green, or neutral dotter), although the number of agents within each status is user-controlled. Whether an individual couples, stays (rests), or intervenes is a stochastic function of the user-controlled tendency values. Additionally, the order in which the agents evaluate each procedure is stochastic. Agent movement throughout the environment is also random.

**Collectives:** As explained in Subsection 2.2, agents are divided into three different statuses: green, red, and neutral dotters. Each status defines a separate collective. These collectives are assigned at the model's initialization, and the size of each of the collectives is determined by the user.

**Observations:** In both models, the number of interventions, number of incidents of violence, and the number of couples formed are recorded throughout each simulation, and the totals are produced as output at the end. These numbers are saved as `num-interventions`, `incidence-violence`, and `num-couples`, and they increase each time a successful intervention occurs, a couple is together for 8 ticks, and a couple forms, respectively. The ratio of the number of interventions divided by the number of total couples is analyzed as a measure of the simulation's effectiveness in preventing acts of interpersonal violence. In Model AM only, the number of interventions executed by neutral dotters with `intervening-slack` is measured. This number is saved as `n.intervention` and the ratio of the number of these interventions divided by the total number of couples is analyzed as a measure of simulation's effectiveness in influencing neutral dotters to intervene.

### 2.5 Initialization

The model is initialized by setting values for the user-defined state variables `num-green-dotters`, `num-red-dotters`, `initial-people`, `coupling-tendency`, `resting-tendency`, and `intervening-tendency`. The agents are placed randomly throughout the environment and everyone is uncoupled. The statuses are chosen so that the first `num-green-dotter` of people become green dotters, then the next `num-red-dotters` become red dotters, and the rest of the agents become neutral dotters.

### 2.6 Submodels

**`setup-people`:** This initializes the agents to be either green dotters, red dotters, or neutral dotters. The total numbers for each of these groups is defined by the user on the model's interface. Irrespective of status, all of the agents are initialized as single/uncoupled and randomly placed in the environment (see `setLocation`). Based on an agent's status, the agent's booleans for `greendotter?` and `reddotter?` are set to true or false accordingly.

**`setLocation`:** This is called by `setup-people` at the initialization of a model simulation. It places the agent in a random location in the environment, making sure to place each agent within at least one patch of the environment's border. This helps ensure proper coupling abilities later in the code. It also faces each agent in a random direction.

**`move`:** This function makes sure that agents do not try to move outside of the environment's boundaries, as world-wrapping does not make sense in this context. Thus, if the patch that an agent is about to move to is a boundary, the agent will turn to face a different direction instead of moving forward. If the patch ahead of the agent is not a boundary, it will move forward 1 patch and then choose a random angle in which to turn. Thus, at the next tick it will start any further movement at this angle.

**`couple` and `uncouple`:** In this model, coupling is equivalent to entering into a potentially dangerous situation, since coupling is only allowed between red dotters and non-red dotters. The `couple` command is only evaluated once a red dotter has decided they want to couple to another individual. Once called, the `couple` procedure asks whether the green dotter or neutral dotter wants to couple. This choice is determined by generating a random floating point number between 0.0 and 10.0. If this number is less than the user-defined `coupling-tendency`, then that individual decides to couple with the red dotter. It also assumes that an agent can only couple with a red dotter who is not already coupled and who is on the patch directly to the agent's right. This coupling behavior was modified from the AIDS module in NetLogo [9]. If successfully coupled, the coupled agents will move to the center of their patches, which turn grey to indicate their updated status. Similarly, to uncouple is to un-do the work of the couple function. Thus, as agents uncouple they re-update their status to be uncoupled and their patch colors return to black.

**`progress`:** This procedure advances the coupled status of a pair at every other tick that a couple has been together. Thus, for the first two ticks, the agents' respective patches are grey. For the next two ticks, the patches are yellow. After they have been together for 4 ticks, the patches turn orange. Finally, after they have been coupled for 6 ticks, their patches turn red (see Figure 1). Regardless of whether patch color is changed, every time this procedure is evaluated, the `couple-length` increases by 1. Once the couple-length has reached a value of 8, the agents uncouple. The time period of 8 ticks was chosen because it was assumed to be an average amount of time a red dotter might spend trying to initiate violence. Thus, `progress` changes the color scheme to provide a visual cue for users to easily see how the interactions are progressing in violence level as the agents stay together for longer periods of time.

## 3 Results

We analyzed the ratio of number of interventions to number of couples from the two models—adaptive (Model AM) and simple (Model SM)—for two population sizes: $N = 100$ ("non-dense") and $N = 200$ ("dense"), resulting in 4 scenarios. We also analyzed the ratio of the number of interventions by neutral dotters only to the number of couples for the adaptive model, for both population sizes. For each scenario, since realistic values of each parameter are unknown, we conducted one-at-a-time sensitivity tests to gain insight into the role certain parameters played in model output.

The default settings for the sensitivity tests were as follows:

- Number of red dotters: 7 (dense: 14)
- Number of green dotters: 15 (dense: 30)
- Number of initial people: 100 (dense: 200)
- Intervening tendency: 5
- Coupling tendency: 5
- Resting tendency: 5
- Number of ticks: 120 (240 minutes)

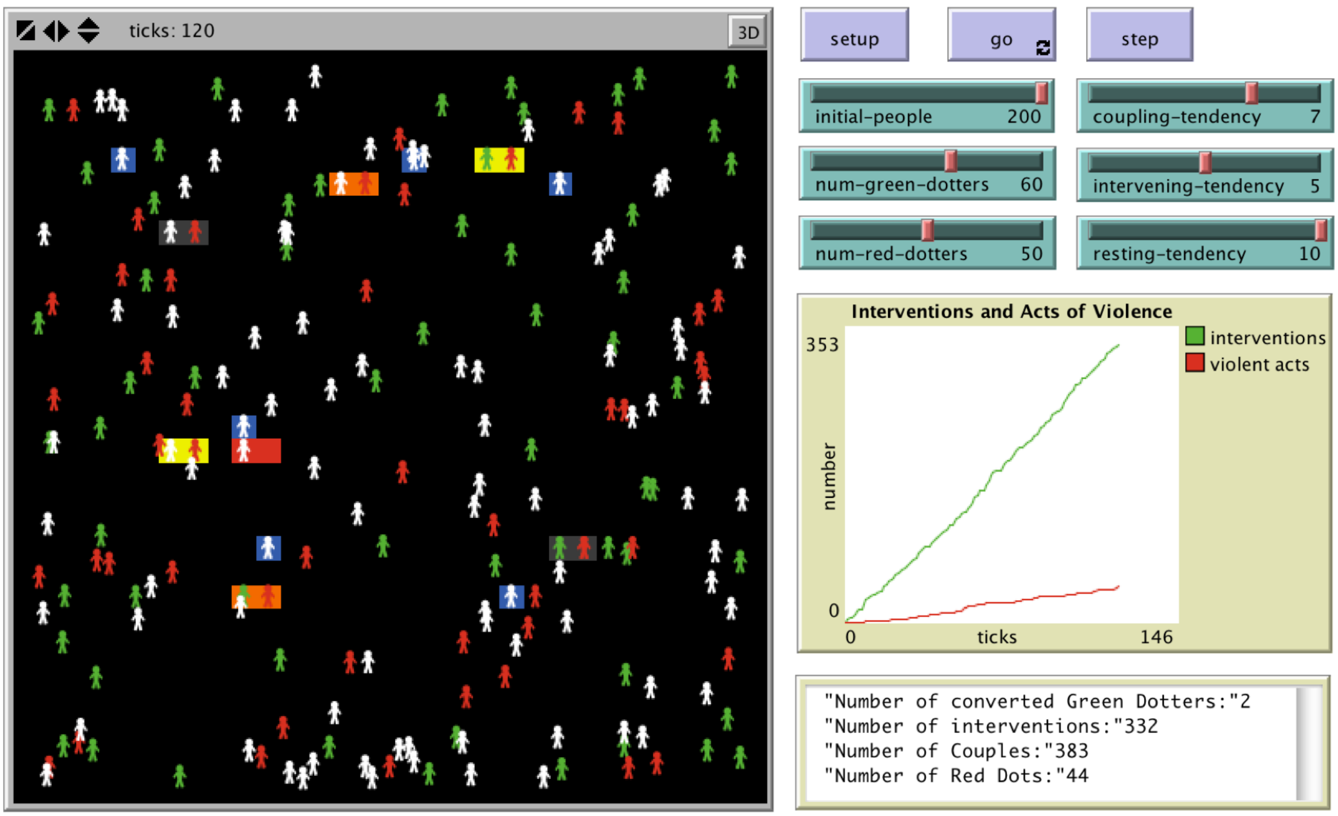



Figure 1: The model's interface. The $41 \times 41$ patch environment contains the agents, colored to indicate their status. To the right of this are the user-controlled sliders and buttons as well as the graphical and text outputs for number of interventions and number of violent acts commited. This simulation was run with a high (perhaps unrealistic) number of red dotters and green dotters so as to better illustrate all of the possibilities that might arise in the interface at any one point in time. Patch color for couples indicates length of time a couple has been together: Grey = 1–2 ticks; Yellow = 3–4 ticks; Orange = 4–6 ticks; Red = 7–8 ticks. Patch color for potential interveners is blue.

The following sensitivity tests were performed for each scenario:

1. Keeping all other parameters fixed at their default settings, vary `coupling-tendency` from 0 to 10 in increments of 1. Repeat each run 100 times.
2. Keeping all other parameters fixed at their default settings, vary `resting-tendency` from 0 to 10 in increments of 1. Repeat each run 100 times.
3. Keeping all other parameters fixed at their default settings, vary `intervening-tendency` from 0 to 10 in increments of 1. Repeat each run 100 times.
4. Keeping all other parameters fixed at their default settings, vary both the number of green dotters from 5 to 30 in increments of 5 and the number of red dotters from 5 to 20 in increments of 5 (non-dense). For the dense scenarios, vary both the number of green dotters from 10 to 60 in increments of 10 and the number of red dotters from 10 to 40 in increments of 10.

Results from each of these tests, for each of the 4 scenarios, are shown in Figures 2–10b. In Figures 2–8, blue circles represent the adaptive model (Model AM) with $N = 100$, and blue squares represent the adaptive model with $N = 200$. In Figures 2–5 red circles represent the simple model (Model SM) with $N = 100$, and red squares represent the simple model with $N = 200$.

### Test 1: Varying `coupling-tendency`

All scenarios exhibit little or no correlation between the total number of interventions to number of couples ratio and the `coupling-tendency` (Figure 2). The jump from `coupling-tendency` $= 0$ to `coupling-tendency` $=$ 1 makes sense because at `coupling-tendency` $= 0$ there are no couples and thus no red dots (acts of violence) or green dots (interventions). Therefore, for `coupling-tendency` $= 0$, the ratio interventions/couples is undefined. For coupling tendencies 1 to 10, this ratio does not increase or decrease in any sort of recognizable pattern, and all of the points hover around the same ratio value. This tells us that, for instance, if the number of couples doubles, the number of interventions should also be observed to double, in order for the ratio to remain fixed. Although the ratio values for the dense models were larger than those for the non-dense models, this difference is not statistically significant.

On the other hand, for Test 1 the ratio of neutral dotter interventions to total number of couples appears to increase linearly for both the adaptive non-dense model and the adaptive dense model (Figure 6). Consistent with the findings for the ratio of total interventions to total number of couples, these ratios are also higher in the dense model than in the non-dense model. However, while there is significant separation between the dense and non-dense scenarios when looking at the neutral interventions/couples ratio (Figure 6), this is not the case in the total interventions/couples ratio (Figure 2).

### Test 2: Varying `resting-tendency`

For Test 2 all scenarios exhibit similar, logarithmic trends, with the total interventions/couples ratio increasing, but at a slower rate as `resting-tendency` is increased (Figure 3). Leaving out the 0 data point (where the ratio is undefined) for the logarithmic fit, the $R^2$ values for the AM, AM Dense, SM, and SM Dense Models are 0.9837, 0.99524, 0.99292, and 0.99476, respectively. There is a difference in the ratios between those for the non-dense models and those for the dense models: for all of the `resting-tendency` values, the dense models' ratios are larger than those of the non-dense models, although in most cases the error bars are too large for this to be a statistically significant difference. However, it is interesting to note that there is some separation of error bars for the higher values of `resting-tendency`, suggesting that in more densely populated areas, if individuals are more likely to stay and watch a situation (around a threshold of 70–80% of the time they are near a potentially violent situation), interventions may significantly increase. Also in Test 2, the ratio of neutral dotter interventions to total number of couples exhibits similar behavior as in Test 1, appearing to increase linearly and producing error bars that do not overlap beginning at `resting-tendency` $= 3$ (Figure 7).

### Test 3: Varying `intervening-tendency`

Similar to what is observed in Test 2, graphs for the ratio of total interventions to total couples produced from Test 3 also all exhibit logarithmic trends, though there is not the same level of separation between the dense and non-dense models at higher levels of the parameter as was seen in Test 2 (Figure 4). The $R^2$ values for the AM, AM Dense, SM, and SM Dense Models are 0.94907, 0.9539, 0.97783, and 0.94907, respectively.

Here, the ratio of neutral dotter interventions to total number of couples does not increase in the same way that it does in Tests 1 and 2 (compare Figure 8 to Figures 6 and 7). In contrast, Test 3 appears to produce a logarithmic trend for both models; however, with the large error bars, a definite pattern is difficult to discern (Figure 8). Regardless, as `intervening-tendency` increases, this ratio either exhibits little change or levels off for both of the models.

**Test 4: Varying numbers of red and green dotters**

The results from Test 4 show that, for all of the models, the ratio of total interventions to couples seems to be more affected by the number of green dotters than the number of red dotters (Figures 9a–10b). Thus, increasing the number of green dotters by 5 (non-dense) or 10 (dense) while keeping the number of red dotters the same resulted in a more dramatic change in the total interventions to couples ratio than changing the number of red dotters by 5 (non-dense) or 10 (dense) and fixing the number of green dotters.

# 4 Discussion

The `coupling-tendency` results (Figure 2) are interesting in that our model indicates that even if someone has a higher tendency to engage in potentially violent situations, the percentage of people affected in the population may not increase that much, or at all. The number of couples continues to increase as `coupling-tendency` increases (Figure 5), so there must therefore be an equal increase in interventions in order for the overall ratio to remain unaffected (Figure 2). This suggests that it might not be as beneficial to minimize the number of potentially violent interactions (a red dotters tendency to "couple") as it would be to increase the number of trained and prepared interveners who are ready to act when they see a potentially violent situation. Green Dot Program educators should make sure to stress the importance of intervening once the green dotter has decided to stay and watch the situation.

The second interesting thing to note is the overall increase in the difference between ratio values for the non-dense models versus the dense models for Tests 2 and 3. Since the proportion of green dotters to red dotters to neutral dotters does not change between these models, we cannot attribute the ratio differences to varying proportions of violent to non-violent agents. The best explanation for this phenomenon is that the denser the environment, the more likely it is that (1) individuals will couple (essentially producing the same result as if `coupling-tendency` were increased) and (2) green dotters will be within the appropriate radius to intervene (in effect, producing a similar result to when `resting-tendency` and `intervening-tendency` are increased).

Further, the graphs produced from Test 1 (Figure 2) have a slope approximately equal to 0. Thus, increasing `coupling-tendency` does not significantly alter the ratio of interventions to couples. However, the graphs for Tests 2 and 3 (Figures 3 and 4) have increasing trends, so increasing the value of these parameters increases the number of interventions to number of couples ratios. Thus, this explains why the denser models "feel", to a greater extent, the effect of increased green dotter proximity (whose activity is controlled by `resting-tendency` and `intervening-tendency`), but not the effect of increased red dotter proximity (whose activity is controlled by `coupling-tendency`). The increased ratios produced by the dense models also signal that these models are constrained less by the percentage of green dotters in the population than they are by spatial constraints. Thus, in less dense environments, a red dotter can become isolated from other green dotters so that it is able to couple without the presence of a green dotter for longer periods of time. This ability for isolation to occur without the knowledge of others in the environment is a likely scenario on college campuses and can emphasize the importance of traveling in groups.

Test 4 can also tell us more about these dynamics of intervention. Although the results serve to reinforce the findings from Tests 1–3, they also shed light on the fact that the ratio of interventions to couples is affected more by increasing the number of green dotters in the population than increasing the number of red dotters in the population. It would be interesting to test even more combinations of green and red dotters in order to see if there is a point at which, no matter the number of green dotters (perhaps even irrespective of the number of red dotters) the ratio of interventions to couples ceases to increase. This could be useful to the Green Dot Program by quantifying a target number of students for the the 7-hour bystander training. This target number could then inform further program design, including efficient allotment of resources for schools implementing the program.

In terms of the ratio of neutral dotter interventions to total number of couples, the most interesting finding is that increasing the `intervening-tendency` did not increase this ratio as much as increasing `resting-tendency` and `coupling-tendency` (Figure 8 compared to Figures 6 and 7). A possible explanation for this is that even though, as `intervening-tendency` increases, there is a higher probability that green dotters will intervene, and thus that neutral dotters will gain `intervening-slack`, the neutral dotters still have a lower tendency to intervene than the green dotters, since their intervening rate is governed by `intervening-slack` instead of `intervening-tendency`. Thus, since in most cases the green dotters are more likely to intervene, the number of interventions by neutral dotters will not be affected as much by an increase in `intervening-tendency`.

Additionally, it makes sense that increasing the `resting-tendency` increases the ratio of neutral dotter interventions to total number of couples so dramatically (Figure 7), since the `resting-tendency` is the same for green dotters and neutral dotters whose

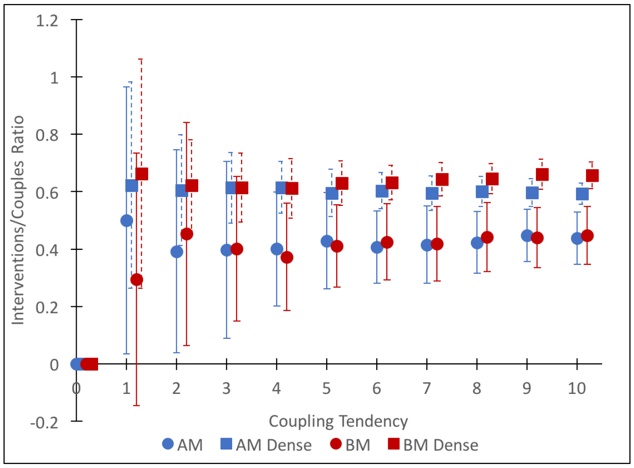



Figure 2: Ratio of the number of interventions to the total number of couples as `coupling-tendency` is varied from 0 to 10 in each scenario (Test 1). Data points represent the mean interventions to couples ratio of 100 simulation runs. Error bars represent one standard deviation above and below the mean.

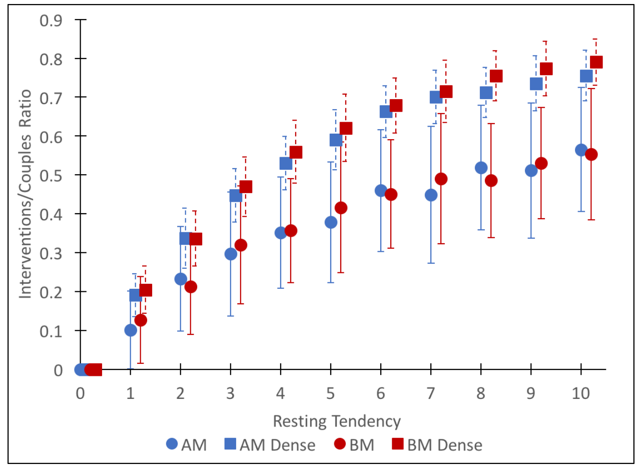



Figure 3: Ratio of the number of interventions to the total number of couples as `resting-tendency` is varied from 0 to 10 in each scenario (Test 2). Data points represent the mean interventions to couples ratio of 100 simulation runs. Error bars represent one standard deviation above and below the mean.

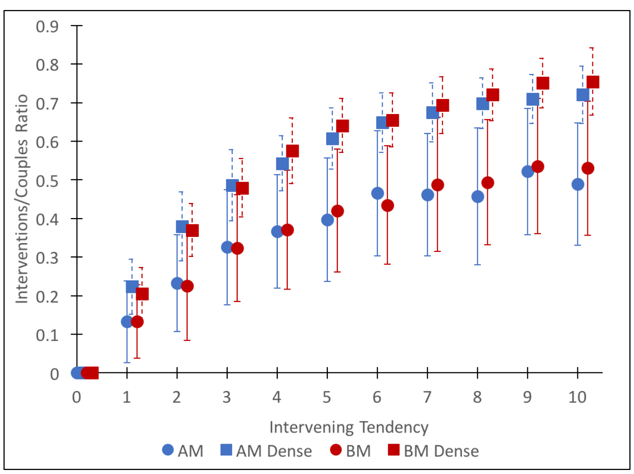



Figure 4: Ratio of the number of interventions to the total number of couples as `intervening-tendency` is varied from 0 to 10 in each scenario (Test 3). Data points represent the mean interventions to couples ratio of 100 simulation runs. Error bars represent one standard deviation above and below the mean.

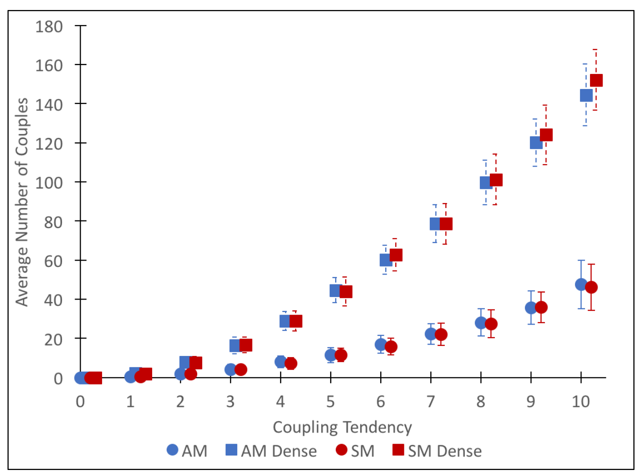



Figure 5: Average number of couples formed per simulation as `coupling-tendency` is varied from 0 to 10 (Test 1). Data points represent the mean of 100 simulations per scenario. Error bars represent one standard deviation above and below the mean.

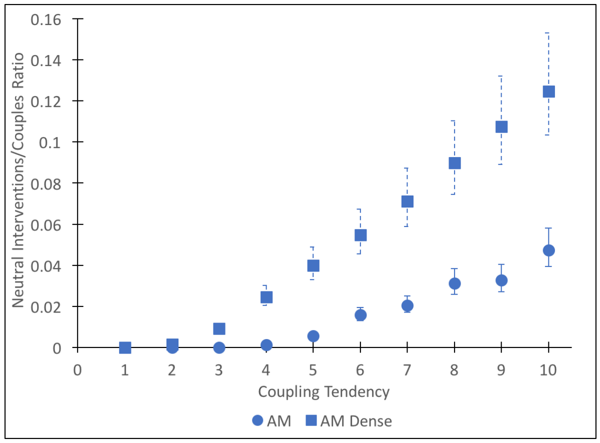



Figure 6: Average number of interventions executed by neutral dotters to total number of couples per simulation as `coupling-tendency` is varied from 0 to 10 (Test 1). Data points represent the mean of 100 simulations per scenario. Error bars are calculated using confidence intervals for exponentially distributed data [11].

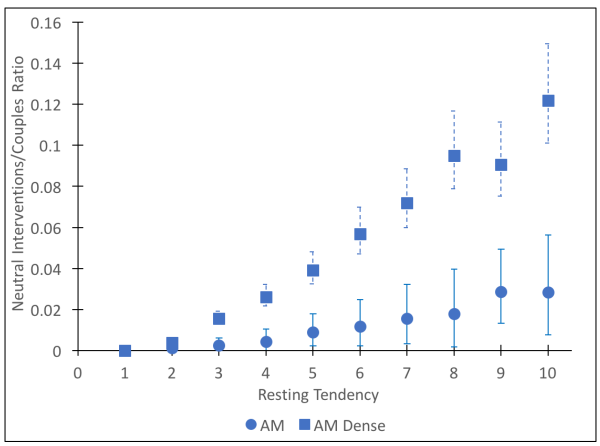



Figure 7: Average number of interventions executed by neutral dotters to total number of couples per simulation as `resting-tendency` is varied from 0 to 10 (Test 2). Data points represent the mean of 100 simulations per scenario. Error bars are calculated using confidence intervals for exponentially distributed data [11].

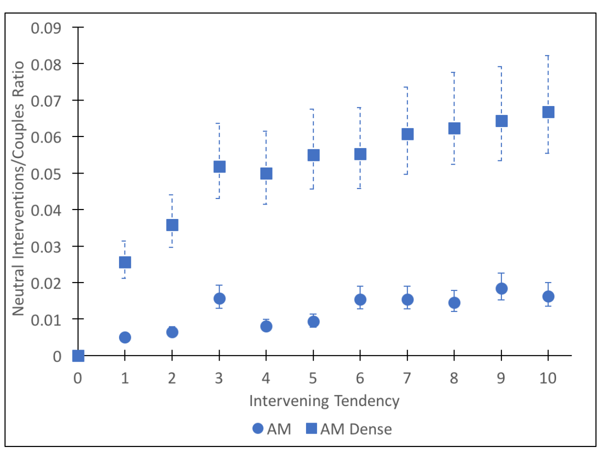
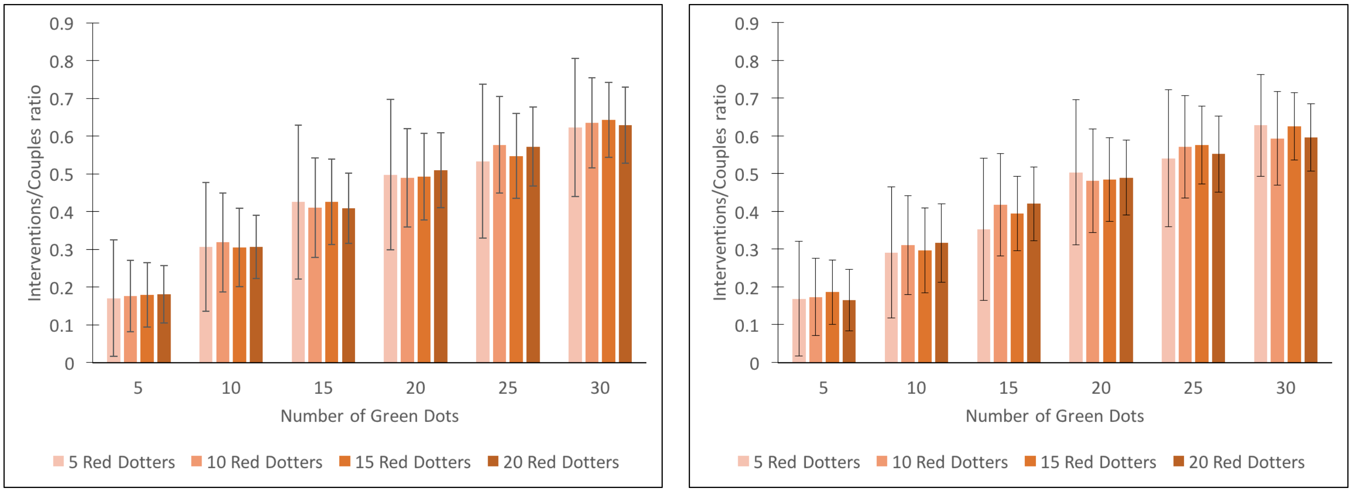
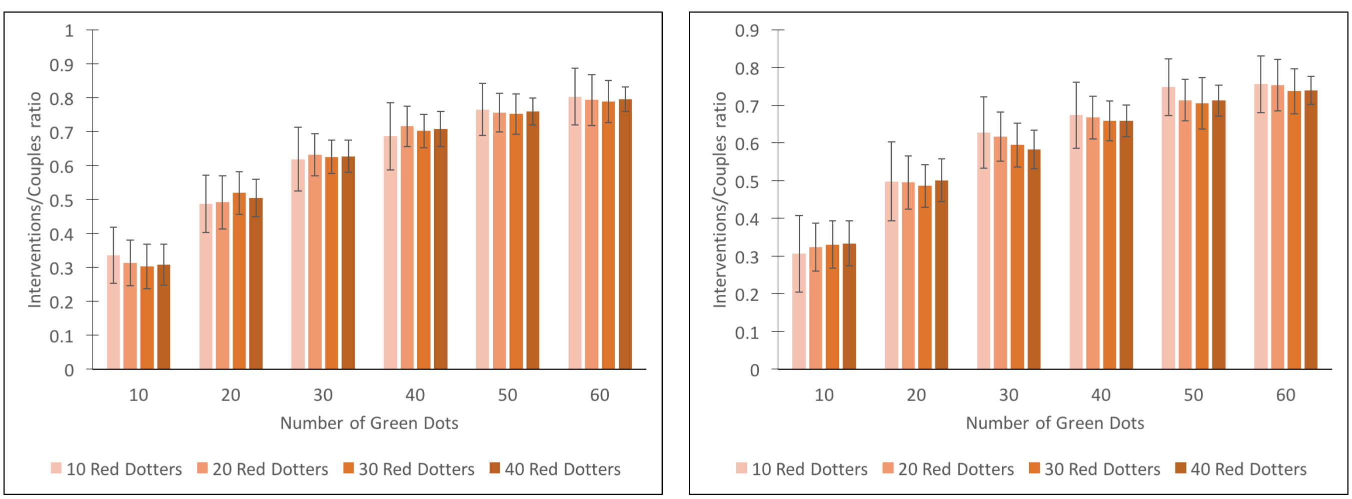



Figure 8: Average number of interventions executed by neutral dotters to total number of couples per simulation as `intervening-tendency` is varied from 0 to 10 (Test 3). Data points represent the mean of 100 simulations per scenario. Error bars are calculated using confidence intervals for exponentially distributed data [11].




(a) Simple Model (b) Adaptive Model

Figure 9: The ratio of interventions to couples as the number of green dotters is varied from 5 to 30 in increments of 5 and the number of red dotters is varied from 5 to 20 in increments of 5 (Test 4). Columns represent the mean of 100 simulations per scenario. Error bars represent one standard deviation above and below the mean.




(a) Simple Dense Model (b) Adaptive Dense Model

Figure 10: The ratio of interventions to couples as the number of green dotters is varied from 10 to 60 in increments of 10 and the number of red dotters is varied from 10 to 40 in increments of 10 (Test 4). Columns represent the mean of 100 simulations per scenario. Error bars represent one standard deviation above and below the mean.

`intervening-slack` is greater than 0. Thus, by increasing this parameter the neutral dotters increase the net probability that they will ultimately intervene.

The most curious trend for the ratio of neutral dotter interventions to total number of couples is found by changing `coupling-tendency` (Figure 6). One potential driver of this trend is that the default values for `resting-tendency` and `intervening-tendency` are large enough that neutral dotters are able to gain enough `intervening-slack` to be tagged as a `potential-intervener` and thus have a higher and higher chance to intervene within the time that a couple is together when there are more couples in the environment. Thus, as `coupling-tendency` increases, the total number of couples increases (Figure 5), but the number of neutral dotter interventions increases more so as to produce the increasing slope in Figure 6. If this is what is happening, we must ask ourselves why the ratio of total interventions to total couples does not increase like this (Figure 2). It is strange that these would not exhibit similar trends, but one possible explanation is that the neutral dotters are "stealing" the `potential-intervener` roles from the green dotters at a high enough rate (probably because there are many more neutral dotters in the population) so that the number of green dot interventions is actually decreasing in such a way that the total number of green dotter interventions plus neutral dotter interventions is consistent with that of the simple model.

# 5 Conclusions and Implications for Violence Prevention

We developed two models of violence prevention, the basic model and the adaptive behavior model, and ran various tests on dense (200 individuals) and non-dense (100 individuals) versions of these models. It is extremely difficult to track actual numbers of violent incidents on college campuses. Thus, instead of using our models to predict precise numbers of interventions over time, we instead focused on how certain aspects of student behavior might affect the level of violence prevention.

On each version of each model, we ran four sensitivity tests: vary the tendency for students to form couples; vary the tendency for green dotters (trained students) and, in the adaptive behavior model, neutral dotters (non-trained and non-violent students) to rest and observe a potentially violent situation; vary the tendency for green dotters (and neutral dotters in the adaptive behavior model) to intervene, after they have chosen to stay and observe; and vary the numbers of red dotters (those intending to harm others) and green dotters in the population. For each test, we gauged the level of intervention by measuring changes to the ratio of the number interventions to the total number of couples formed throughout the simulation.

Our results are important to the Green Dot Program's implementation because they reflect the power of the bystander approach. There are questions around whether training bystanders is more or less effective than training individuals to not engage in potentially violent situations. Due to trends exhibited by each of the sensitivity tests, our study suggests that increasing the tendencies to stay and observe a situation and then to intervene (i.e., improving bystander training effectiveness) is more powerful in reducing interpersonal violence than reducing their tendency to couple (i.e., trying to prevent the situations from initially arising). Although this type of training is already taking place, there are other aspects of interpersonal violence prevention training that could perhaps be pared down in turn to allow for more emphasis on this component. For example, focusing the training more on the specific methods of intervention may not be as influential as teaching trainees ways in which they can notice potentially violent situations in the first place and stay and observe the situation, even if they may feel uncomfortable or that they are invading the group's privacy.

Results from our comparisons of the dense and non-dense models reveal the importance of traveling in groups to parties or other scenarios where violence is more likely to occur, since the more dense the environment, the more likely there are others around who will see potentially violent situations before they have a chance to escalate. This important finding should be emphasized during Green Dot trainings. The Green Dot program could also use our modeling efforts to obtain target numbers of students to train in the Green Dot philosophy, by observing threshold values of interventions as the number of green dotters is increased.

Interestingly, in most all tests, the adaptive models more frequently produce smaller ratios (albeit not significantly smaller) than the simple models. This is especially true in comparing the dense models, but not as consistent with the non-dense models. This trend is contrary to the philosophy behind the Green Dot curriculum, which is that interpersonal violence can be combatted by students learning from each other. One possible explanation for why this result was observed is that neutral dotters that gain `intervening-slack` have the same tendency to rest as green dotters do, but, in general, possess a much smaller tendency to intervene, since their `intervening-slack` starts at 0 and increases only by 1 unit each time they witness a nearby intervention. Since these models only allow one `potential-intervener` per couple, the neutral dotters may be "stealing" this role but not intervening quite as much as a green dotter would, because their intervening-tendency is too low; as a result, the total number of interventions decreases. Because it is not always realistic that one person is involved in an intervention if there are others around to help, future work should include allowing multiple interveners per couple. Additionally, we may want to consider decreasing the `resting-tendency` for the neutral dotters that have low values of `intervening-slack`. This result does shed light, however, on the importance of the role of neutral dotters (untrained interveners). In order for violence prevention to be optimized, the Green Dot program should focus efforts on how to teach green dotters to lead by example, so that once another person witnesses an intervention, they are quickly and adequately prepared and inspired to take action in the future.

## 6 Future Work

In addition to some modifications previously mentioned, there are several other elements that would be interesting to add to this model. The first attribute that we would like to add is the creation of different environments in the NetLogo space, thus making the model environment more realistic. For instance, for a model of a college campus, there could be a "Party Environment", a "School Day Environment", and a "Sleeping Environment".

Additionally, we would like to experiment with the effect of peer involvement. If there are more green dotters within a certain radius of a coupling, will the likelihood of an intervention increase? If there are a large number of neutral dotters (without `intervening-slack`) also within this radius, should the likelihood of an intervention decrease due to bystander apathy or fear of involvement? Further, the tendency for a green or neutral dotter to intervene could be made to increase as the patch colors increase (i.e., as the couple stays together longer). These would be interesting concepts to implement so that our model reflects more accurate social behaviors.

A future model might also include changed behavior of the survivor after a red dot event or a certain probability that a red dotter could be converted to a green dotter. It would also be interesting to see what happens when we take into consideration the gender of each person. This would require more research into the rates at which men and women commit acts of violence in order to integrate more realistic parameters. In addition, a future model could incorporate the effects that relationships have on the rates of interpersonal violence, since a high percentage of interpersonal violence occurs amongst people who know each other. This added feature could possibly provide an interesting approach to how acts of interpersonal violence could be better prevented.

With all of these models, we would like to perform a global sensitivity analysis, which involves changing more than one parameter at a time. Global analysis could provide more insight into how our output of interest is affected by each parameter, especially when certain parameters act concurrently to produce a given result. Such analysis would therefore shed even more light into ways we could improve upon the Green Dot violence prevention effort and thus help to make our college environments safer for all.

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